GLOBAL CHANGES OF THE SEISMICITY OF THE EARTH

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Introduction

Beginning in 2010 was marked by a number of natural disasters on a global scale. One after another powerful earthquake in the Solomon Islands (January 3), Haiti (January 12), off the coast of Chile (27 February), on the border of California and Mexico (April 4), China (April 13). Apogee were two very powerful volcanic eruptions. The largest over the past half-century eruption in Chile. Giant eruptions in Iceland suspended for several days, the aviation industry in many countries.

A powerful earthquake struck Haiti on Jan. 12, 2010. His moment magnitude of Mw = 7.1. Almost completely destroyed the city of Port-au-Prince - the capital and main port of Haiti. Under the ruins of the city literally disappeared into densely populated neighborhoods. Killed over 270,000 people. Millions of people were left homeless.

One of the largest earthquakes in the past half century occurred off the coast of Chile on Feb. 27, 2010. It had a magnitude of Mw = 8.8, accompanied by a tsunami and led to numerous casualties and destruction. Its epicenter was 90 kilometers from the capital of the Bio-Bio Concepcion, the second largest city in the country after Santiago. Magnitude of the strongest aftershocks reached Mw = 8.0. The death toll from the tsunami was minimal, since most of the inhabitants managed to escape the coast in the mountains. The earthquake on Feb. 27, 2010 was the largest after the Chilean earthquake of May 22, 1960 with Mw = 9.5, occurred at 230 km to the south.

Extremely strong earthquakes continue as at present. This article shows that this global geological activation is not accidental.

Global Seismogeodynamics

The results obtained in this work are based on the new methodological approach to the study of the Earth's seismogeodynamic regime according to which the flow of seismic events is analyzed not integrally but in magnitude intervals reflecting the geodynamics of the hierarchical fault–block structure of the geological medium [1, 2].

In this article sequences of large earthquakes that occurred throughout the Earth in the period from January 1996 to May 2010 were the subject of study. These earthquakes were differentiated in the magnitude intervals $M = 8.5 \pm 0.2$, $M = 8.0 \pm 0.2$, $M = 7.5 \pm 0.2$,and $M = 7.0 \pm 0.2$, completely overlapping a wide energy range, from $M = 6.8$ to $M = 8.7$. The last interval also included several large earthquakes of $M \geq 8.8$.

Figure 1 shows the position of all seismic sources. . Light gray painted sources, located at the depth of 70 km or less; dark gray color shows the sources deeper 70 km. These earthquake sources coincide with zones of subduction (sinking lithosphere in the mantle of the Earth). Date of show only those earthquakes that are cited in the text. Circles delineated foci of earthquakes in Alaska (1964) and Chile (1960). Thin gray lines - the boundaries between lithospheric plates.

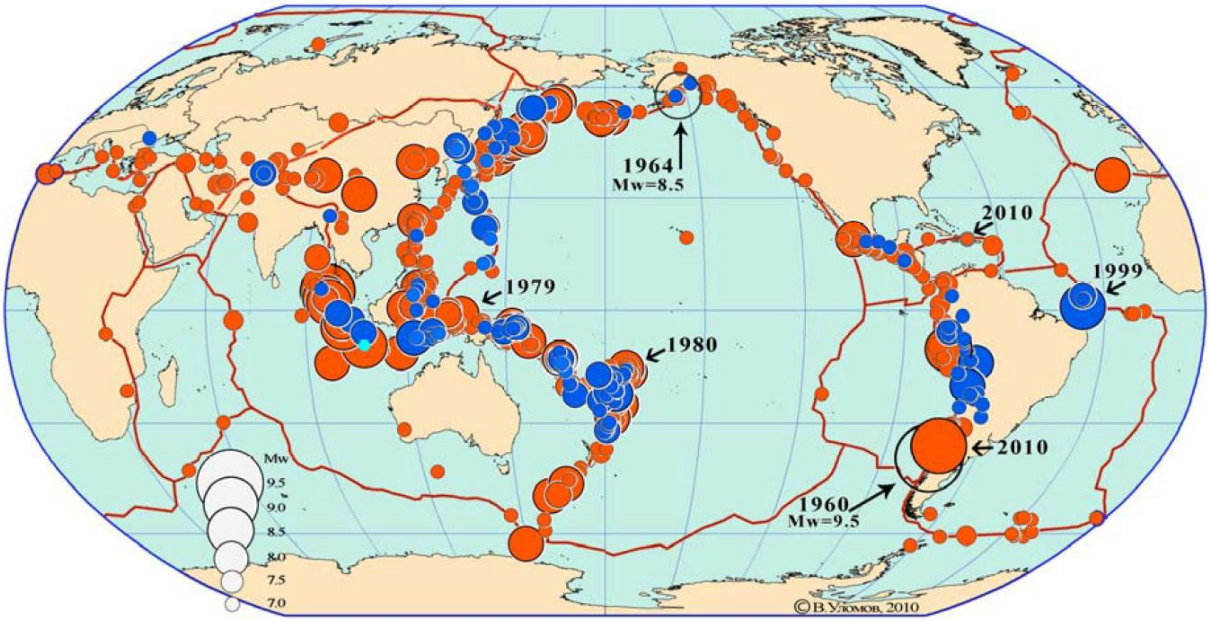

Fig. 1. The epicenters of major earthquakes of the Earth for the period from January 1996 to May 2010. Scale of earthquake magnitude is shown at the bottom left For the territory of Russia shows the state border.

Cumulative plots characterizing the accumulation rate of seismic events all over the Earth in the studied magnitude intervals are presented in Fig. 2. It should be noted that this figure, as in Fig. 1, borrowed from the paper [2], which was submitted for publication in the middle of September 2006, and in this article is completed until May 2010.

In Fig. 2, the cumulative number of earthquakes and the years of their occurrence are plotted on the abscissa and ordinate axes, respectively. Events with hypocenters in the depth ranges $h \leq 70$ km (shallow events) and $h > 70$ km (deep events) are shown by light gray and dark color circles, respectively. The linear approximations (dotted lines) are actually everywhere characterized by the high correlation coefficient (0.9 or higher).

Because of a very large number of shallow earthquakes with $M = 7.0 \pm 0.2$, only the fragment of the corresponding plot is presented in the inset in Fig. 2 (line 4).

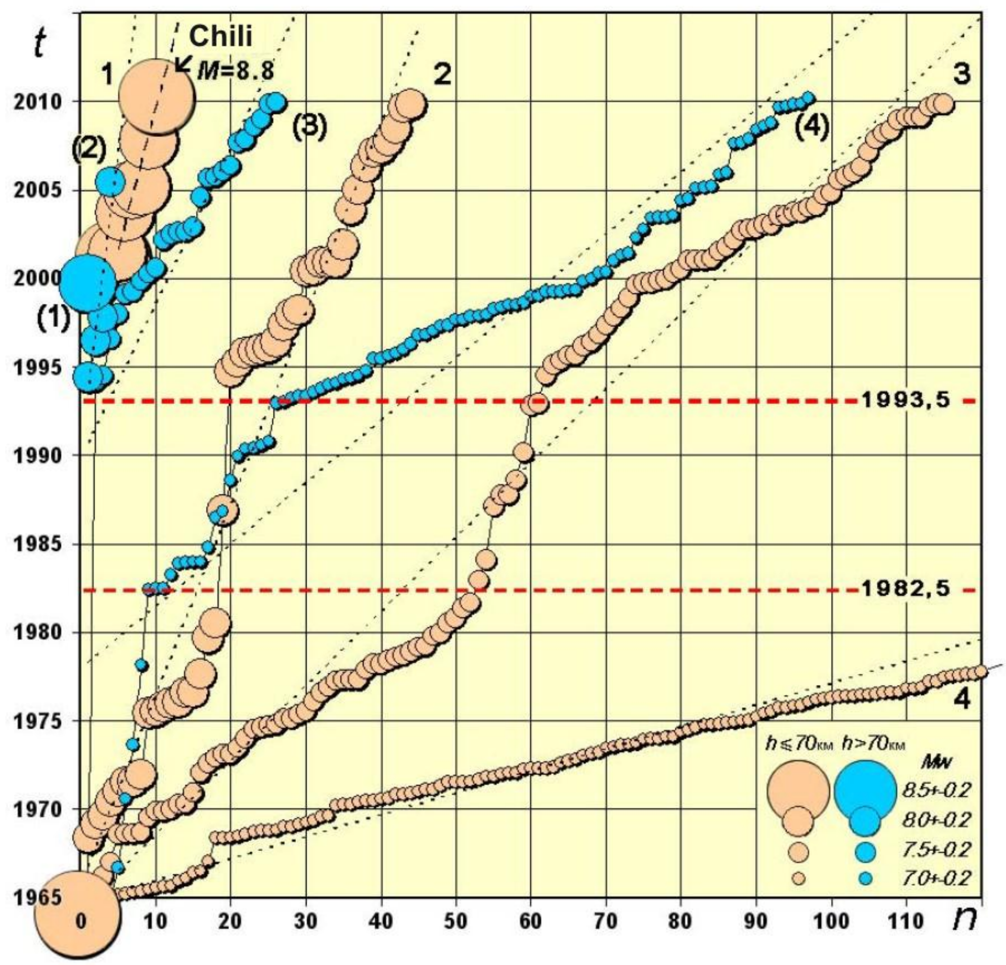

Fig. 2. Cumulative plots of the accumulation of global seismic events with the magnitudes 8.5 ± 0.2, 8.0 ± 0.2, 7.5 ± 0.2 , and 7.0 ± 0.2 that occurred in the period from January 1996 to May 2010: 1 – 4 - linear approximation of the occurrence times of earthquakes with hypocenters no deeper than h = 70 km ; the epicenter of the November 13, 2006, earthquake with M = 8.3 is encircled by a dotted line; (1) – (4) the same for seismic events with hypocenters at depths h > 70 km.

The slopes of the approximating lines characterize the accumulation rates of seismic events of the corresponding magnitudes: the smaller the slope of a line, the higher the rate. A steepness increase reflects a decrease in the recurrence rate of earthquakes. If earthquakes occurred rhythmically, i.e., with the same frequency in each sequence, all their occurrence times, in particular, during the entire period under consideration, would lie exactly on straight lines. However, in reality, deviations from this pattern are caused by a nonlinear development of geodynamic processes affecting the stress–strain state of the medium and, accordingly, seismicity manifestations. Analysis of the configurations of the cumulative plots revealed an interesting phenomenon reflecting specific features of the temporal evolution of global seismogeodynamic processes. First of all, we mean a substantial slowdown in the recurrence of all shallow earthquakes during the approximately 11-yr time interval (from the middle of 1982 through the middle of1993) bounded by the horizontal dashed lines in Fig. 2. As is seen from the figure, the accumulation rates of events in the considered magnitude intervals change rather rapidly, which is expressed in abrupt bends in all plots at the ends of the anomalous interval (1982.5–1993.5). However, before and after there veiled relative seismic quiescence, the occurrence frequency of shallow earthquakes not only was substantially higher but also was characterized by virtually the same accumulation rate of seismic events. In order to compare the occurrence frequencies of earthquakes within the magnitude ranges under consideration, the numbers of events in 11-yr time intervals before (1971.5–1982.5), during (1982.5–1993.5), and after (1993.5–2005.5) the seismic quiescence are given in the table.

Numbers of earthquakes of various magnitudes in the regular intervals before, during, and after the anomalous seismicity

Hypocentral depths h ≤ 70 km				
Y, годы	M=7.0±0.2	M=7.5±0.2	M=8.0±0.2	M=8.5±0.2
1993.5–2005.5	141	39	17	4
1982.5–1993.5	40	9	1	0
1971.5–1982.5	111	36	12	0
Average	97	28	10	~1
Hypocentral depths h > 70 km				
1993.5–2005.5	53	12	4	1
1982.5–1993.5	22	0	0	0
1971.5–1982.5	2	0	0	0
Average	26	4	~1	~ 0

The average recurrence rates of shallow and deep earthquakes in the corresponding magnitude intervals are also presented in the table. They virtually coincide with the values taken from the generally accepted integral recurrence plots of earthquakes of the Earth. This fact and the aforementioned completeness of the analyzed earthquake catalog confirm the realistic nature of the results obtained.

In all cases, the time is measured from the middle of the year, as in the anomalous period of seismic quiescence. It is seen that, in the interval 1982.5–1993.5, earthquakes with M = 7.0 ± 0.2 and 7.5 ± 0.2occurred three to four times, and earthquakes with M =8.0 ± 0.2 ten or more times, less frequently than in the preceding and subsequent 11-yr periods. The largest seismic events with M = 8.5 ± 0.2 and more, which were altogether absent during the first two intervals, started to occur nearly annually from 2001 through 2006. They included the catastrophic earthquakes of December 26, 2004, with M = 8.8 and March 28, 2005, with M = 8.5, which occurred off the Sumatra coast and were accompanied by gigantic tsunamis that caused numerous victims. The previous 1964 Alaska earthquake with M =8.5 was equally large, and the time interval under consideration began actually from this earthquake.

The fact that deep seismic activity began immediately after the general quiescence of the shallow seismicity is no less important (see Fig. 2). No earthquakes with magnitudes M = 7.5 ± 0.2 and higher were observed before this period, whereas twelve earthquakes with M = 7.5 ±0.2, four earthquakes with M = 8.0 ± 0.2, and one earthquake with M = 8.8 occurred in the conclusive time interval. The last earthquake was unique in its magnitude and occurred in the Atlantic Ocean at a depth of about 90 km off the eastern coast of South America (see Fig. 1). However, earthquakes with M = 7.0 ± 0.2 occurred very seldom up to their conclusive active stage. Thus, while five such earthquakes occurred annually from the middle of 1993 and later, their recurrence rate in the period of seismic quiescence was lower by a factor of 2.5 (and before, even by a factor of 26.5).

The extremely high global seismic activity will continue on today.

The nature of planetary changes in the seismic regime can be interpreted in terms of contemporary ideas of the global dynamics of lithospheric plates (seismicity is its most impressive manifestation). Thus, events with h > 70 km associated with the subsidence of lithospheric plates into the upper mantle in subduction zones, island arcs at the periphery of oceans, and relicts of such zones on continents (for example, the eastern Carpathians; at the NW and SE terminations of the Himalayas; Crimea-Caucasus-Central Caspian region). Shallow sources are widespread mainly on continents and in oceanic rift zones. However, both types of sources are undoubtedly caused by a coherent seismogeodynamic process encompassing the entire Earth as a whole.

In order to explain the observed pattern of global seismogeodynamics in the period under consideration, we cannot exclude at least the two following scenarios.

Thus, it may be assumed that the general seismic quiescence in this period was caused by a slow (creep like) and virtually aseismic subsidence of the lithosphere in subduction zones, weakening the total stress state in the lithosphere and decreasing the number of seismic movements in it. Due to the temporary absence of significant hooks (barriers) on sliding planes, no large earthquakes occur in subduction zones (see Fig. 3).

According to another scenario, the observed general seismic quiescence is, on the contrary, associated with the accumulation of geodynamic stresses in the lithosphere of continents and oceans, due to, among other factors, the slowdown of lithosphere subsidence processes in subduction zones. After active subduction is resumed, a general release of lithospheric stresses begins and the entire depth range becomes active.

Other explanations are also possible. Nevertheless, the observed clearly expressed quiescence and other changes in the seismic regime in the entire depth range of seismic sources are an indisputable fact, and the nature of this phenomenon is associated with specific features of the Earth’s geodynamic development. It is also possible that both scenarios took place simultaneously but were realized differently innumerous subduction zones.

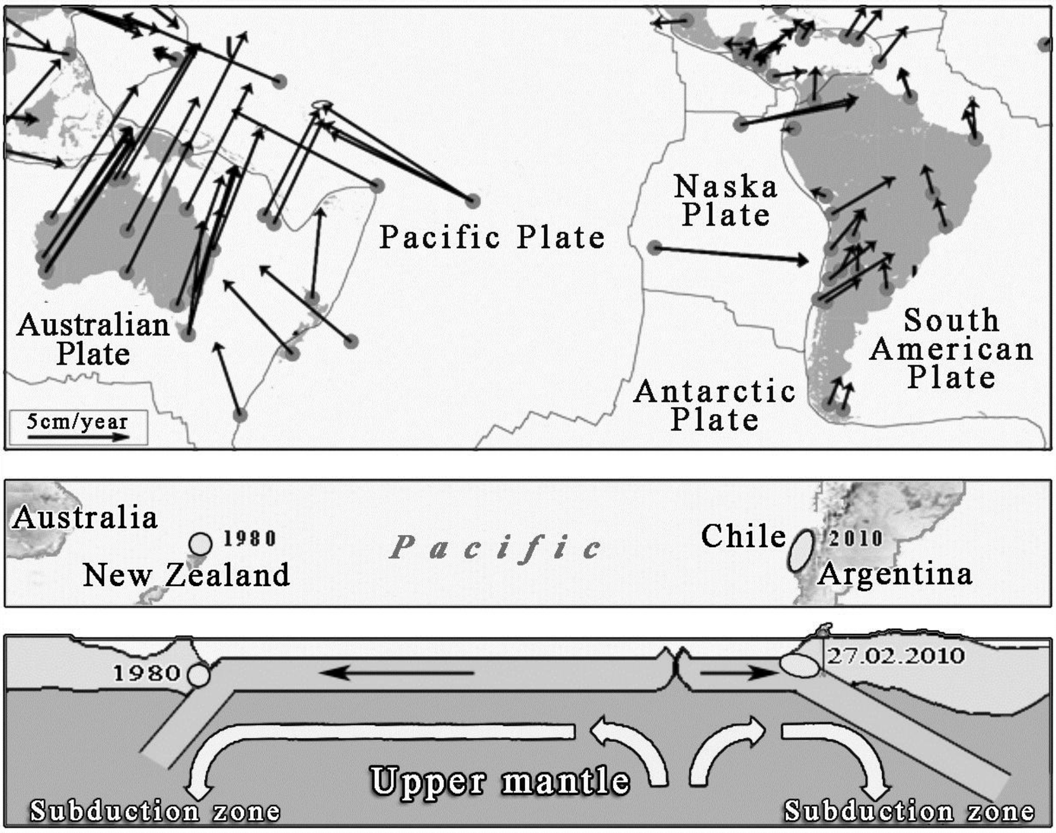

Fig. 3. Directions and velocities of motions of lithospheric plates on the territory between Australia and South America.

Figure 3 illustrates the directions and velocities of contemporary horizontal motions of lithospheric plates determined from GPS (by NASA) measurements at sites on continents and islands (above). Boundaries between plates are shown by thin lines. In the center - a fragment of territory from Australia to South America, along which made the vertical section of the lithosphere and upper mantle (below). At the bottom of the large arrows show the convection in the Upper mantle of the Earth, and thin black arrows show the movement of the Pacific and Naska plates. The New Zealand earthquake 1980 and earthquake 1979 (see Fig. 1) were the last events of which came after nearly 15-year period of anomalous seismic lull.

Joint investigations of seismogeodynamic and hydrogeodynamic processes allowed us to reveal a certain synchronism between changes in the seismic regime of the Earth and the ocean water surface level. In this respect, the joint analysis of seismogeodynamic and hydrodynamic processes performed in seismicity studies of the Caspian Sea has an important advantage, because the only short subduction zone in the central Caspian Sea was considered in [3]. The Caspian Sea and the ocean are similar in that both are closed water basins and can be regarded as indicators actively responding to global and regional seismogeodynamic processes.

As distinct from the Caspian Sea with its single subduction zone, the hydrologic regime of the ocean can be related to a great number of such zones, including those located on the periphery of the Pacific Ocean. Some subduction zones can be activated, whereas the lithosphere subsidence in other zones slows down. Nevertheless, the relation of ocean level variations to seismic regime changes in the period 1982–1993 is recognizable in this case as well. Note that such a rapid ocean level drop started immediately after two large (M =8.0 ± 0.2) earthquakes that occurred in the SW, Indonesian part of the Pacific Ocean in 1979 and 1980 and concluded the long series of similar events before the seismic quiescence of 1982–1993. In this respect, it is interesting that, according to observations of oceanologists, the most intense variations were observed after1993 precisely in this part of the Pacific Ocean.

It is equally important that even supporters of the ideas of a nearly absolute influence of temperature on ocean level variations had to admit that some values obtained in the period considered by them (1993–2003) cannot be accounted for by temperature changes alone [4].

Conclusion

A large number of various factors, including dynamics of lithospheric plates and global seismicity, control the geological formation and the water surface level on the Earth. However, these factors mentioned above have not received proper attention as yet, although the interrelation of seismogeodynamic and hydrogeodynamic processes and phenomena has long been known at the level of regional and source seismicity [5].

The Earth is a structurally complex dynamic system, and the modern system approach should be applied to the study of processes developing under strongly non-equilibrium conditions of its geospheres, with their inherent self-organization phenomena.

Dynamics of the Earth's crust and the whole lithosphere is due to the accommodation processes of volumes of the geophysical medium to applied long-term force actions, including those on the planetary scale. From this standpoint, the alternation of increases in elastic stresses with their subsequent releases in the form of slow deformations or rapid stress drops in earthquake sources is the most efficient self-organizing regime of geodynamics. The fractal structure of the medium predetermines its specific response to external deformations. Thus, in the case of weak forces applied to the medium, the seismic regime is nearly stationary and characterized by the occurrence of weak earthquakes. If the forces increase, for example, as a result of large seismic or creep motions, the seismogeodynamic system is transformed into a qualitatively new and more organized state and sources of large earthquakes interrelated in space and time arise.

Although the geodynamic system continuously changes its state, the Earth as a whole is in dynamic equilibrium, which is favored by the observed periodicity of the accumulation and release of geodynamic stresses.

References

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